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Effects of landscape matrix and plantations on birds in tropical rainforest fragments of the Western Ghats, India

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Cover
An aerial view of a fragmented landscape of rainforests and plantations in the Western Ghats. *(Photograph: M. D. Madhusudan)*

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Effects of landscape matrix and plantations on birds in tropical rainforest fragments of the Western Ghats, India

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By

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Abstract

As large nature reserves occupy only a fraction of the earth's land surface, conservation biologists are critically examining the role of private lands, habitat fragments, and plantations for conservation. This study in a global biodiversity hotspot and endemic bird area, the Western Ghats mountain range of India, examined the effects of connectivity of rainforest fragments with shade-coffee plantations and the influence of habitat structure and floristics on tropical rainforest bird communities. Systematic sampling for habitat and birds was carried out in 13 sites, including six fragments (three relatively isolated and three with canopy continuity with adjoining shade-coffee plantations and forests), six plantations differing in canopy tree species composition (five coffee and one cardamom), and one control site containing a large relatively undisturbed primary rainforest in the Valparai plateau of the Anamalai hills. Around 3300 detections of about 6000 individual birds belonging to 106 species were obtained. The plantations were depauperate in relation to rainforest in rainforest bird species, particularly endemic species, but one site (cardamom plantation) with an entirely native canopy of tall rainforest trees, had species richness and bird abundance values comparable to that of primary rainforest. Plantation and fragment sites that were less isolated (more canopy continuity in surrounding landscape) tended to support greater number of rainforest and lesser number of open-forest bird species and individuals than more isolated sites. Rainforest bird richness and abundance were positively related to the vegetation component representing densities of woody plants, canes, lianas, and bamboos. Bird community composition was however related only to floristic (tree species) composition of sites. The results indicate that the maintenance or restoration of such attributes in plantations and fragments can aid in bird conservation in the region. The potential of rainforest fragments and shade-coffee and cardamom plantations for bird conservation outside wildlife protected areas is emphasised.

1. Introduction

Habitat fragmentation threatens the survival of wildlife species throughout the world. In tropical rainforests known for their high biological diversity (Richards 1996, Wilson 1992), habitat loss has been acute. Between 1979 and 1989, about 150,000 km² of tropical rainforests were lost to deforestation around the world and most previously pristine landscapes are likely to contain only fragments and secondary forests during this century (Brown and Lugo 1990, Whitmore 1997). As large rainforest tracts are converted to 'islands' in a 'sea' of altered and developed areas, the survival of many wildlife species will hinge upon their ability to persist in human-modified landscapes and on our efforts to conserve and manage these species and habitats. Unlike true islands, most forest fragments are not surrounded by a sea of inhospitable or ecologically neutral environments (Wiens 1994). The altered habitats in the surrounding landscape matrix are a source of potential colonists as well as being suitable for colonisation by species that can persist in such habitats. The ability of species to survive in fragments may thus depend on surrounding habitats and whether the species uses such habitats (Stouffer and Bierregaard 1995a,b, Laurance *et al.* 1997, Renjifo 2001). In addition to this landscape-level approach to conservation of rainforest fragments, increasing attention is being paid to the conservation values *per se* of lands outside conservation reserves that may include habitat fragments, secondary forests, private lands, and countryside habitats such as shade-coffee plantations (Brown and Lugo 1990, Turner and Corlett 1996, Daily 2001). Approaches that supplement habitat protection efforts by conserving wildlife habitats adjoining protected areas, increasing landscape-level connectivity of patches, and restoring degraded areas are thus gaining ground as a means to conserve biological diversity (Laurance and Bierregaard 1997).

The Western Ghats hill ranges of India typify many of these conservation problems. This hill chain is recognised as one of the eight 'hottest hot spots' of biological diversity in the world (Myers *et al.* 2000) and among the Global 200 most important eco-regions (Olson and Dinerstein 1998) and Endemic Bird Areas (Stattersfield *et al.* 1998). The Western Ghats faces severe threats from human disturbance due to deforestation, developmental activities, conversion to plantations, and habitat fragmentation (Nair 1991). Menon and Bawa (1997) estimated that, between 1920 and 1990, forest cover in the Western Ghats declined by 40%, resulting in a four-fold increase in the number of fragments, and an 83% reduction in size of forest patches. This is not surprising given that this region is one of the hotspots with the highest human population densities (Cincotta *et al.* 2000).

One of the major causes of forest fragmentation in the Western Ghats is the spread of plantations, particularly tea, coffee, and *Eucalyptus*. The area under plantations is large and growing. Tea plantations in the south Indian states increased by 17.7% in the period 1987-1998 from 74,765 ha to 87,993 ha (Tea Board 2002). Large areas of *Eucalyptus* plantations also occur with tea as it is used as fuel-wood for tea-curing in the factories. Similarly, during 1999-2000, the US$ 447 million Indian coffee industry had plantations of about 340,306 ha, almost entirely in the Western Ghats region of southern India, having increased in area coverage by 25.7% from 270,821 ha in 1990-1991 (Coffee Board 2001). These coffee plantations, particularly where grown traditionally under the shade of native forest trees, form a substantial area of forest canopy cover in the Western Ghats.

The effects of such habitat fragmentation and conversion to plantations can be effectively addressed by studies of bird communities which form useful indicators of ecological changes and habitat alteration (Furness and Greenwood 1993, Raman and Sukumar 2002). The Western Ghats also contains 16 species of restricted-range birds including 12 of near-threatened conservation status (Stattersfield *et al.* 1998). A recent assessment reports that the Western Ghats supports populations of one endangered, three vulnerable, and seven near-threatened bird species, of which all but two inhabit tropical rainforests (BirdLife International 2001). This study

examines the conservation of tropical rainforest birds in the man-modified landscape of the Anamalai hills in the southern Western Ghats of India. The study had two principal objectives:

1. What is the influence of the landscape matrix adjacent to or surrounding fragments on tropical rainforest birds? This question is explored by comparing fragments that are surrounded by shade-coffee plantations or adjoin other forest types with those that are "isolated" being surrounded by tea plantations, a relatively inhospitable habitat for birds.
2. What is the influence of the composition of the shade tree species mixture in coffee estates on the bird community? Plantations with canopy tree species composition ranging from a near-monoculture of exotic species to those that had virtually entirely native rainforest trees were compared with each other and with relatively undisturbed rainforest to test the hypothesis that greater similarity in tree species composition with rainforest supports a more similar tropical rainforest bird community.

2. Study Area

2.1 *The Western Ghats*

The Western Ghats is a 1,600 km long chain of hills running along the west coast of the Indian Peninsula (8°-21° N). The chain of hills is interrupted by the 30 km wide Palghat Gap at around 11° N, and a few other minor gaps along its length. This unique biogeographic province (Mani 1974, Rodgers and Panwar 1988) has pronounced north-south, east-west, and elevational gradients, which have profound consequences for the distribution of plants and animals. The southern end of the Ghats has a short dry season (2 – 5 months) as it receives rain from the southwest (June – September) and northeast (October – January) monsoons. The northern reaches have a longer dry season (5 – 8 months), receiving rain mostly during the southwest monsoon. The average annual rainfall in the evergreen forests ranges from around 1,800 to 7,500 mm depending on the locality (Pascal 1988, Daniels 1992).

Most of the higher hills (1,000 – 2,000 m) in the Western Ghats are found towards the south, between 8° N and 13° N. Pascal (1988) has classified the tropical wet evergreen forests of the Western Ghats into low (< 700 m), medium- (700-1,400 m), and high-elevation (> 1,400) m types. Moist forests, including tropical wet evergreen rainforest, are found largely south of 16° N, particularly south of the Palghat Gap, a region often called the southern Western Ghats. This is also the region that contains higher diversity and a greater number of endemics of rainforest plant and animal taxa (Nair and Daniel 1986, Daniels 1992, Vasudevan *et al.* 2001, Ishwar *et al.* 2001, Ali and Ripley 1983).

2.2 *The Anamalai hills*

The Anamalai (which in Tamil, the local language, means the elephant hills) ranges are a major conservation area in the southern Western Ghats. Although much of the key mid-elevation tropical evergreen forest of interest to this study occurs in the Indira Gandhi Wildlife Sanctuary (987 km², 10° 12' N to 10° 35' N and 76° 49' E to 77° 24' E), many of the rainforest fragments occur in private lands on the Valparai plateau (Figure 1). The natural vegetation of this region, receiving around 3,000 mm of rainfall annually particularly during the southwest monsoon (June – September), has been classified as mid-elevation tropical evergreen forest of the *Cullenia-Mesua-Palaquium* type (Pascal 1988). The Valparai plateau contains a large area of tea, coffee, and cardamom estates occupying around 200 km² and lying almost in the centre of four Wildlife Sanctuaries and National Parks and a large tract of Reserved Forest. The plateau has a small town (Valparai) and a human population of over 106,000 people (1991 Census), mostly estate labourers, scattered across the town and estates.

At least 25 rainforest fragments have been identified so far in and around the Valparai plateau (Umapathy and Kumar 2000) and additional sites do exist. Besides two large fragments

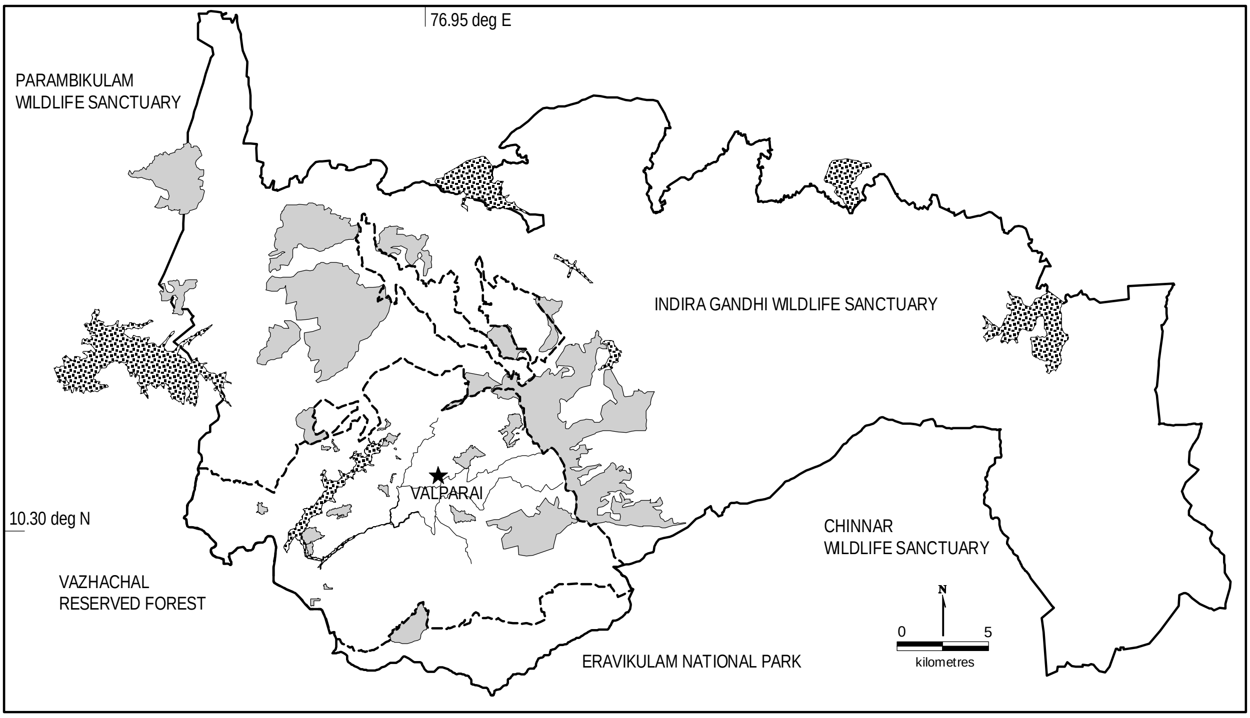

Figure 1: Map of the Indira Gandhi Wildlife Sanctuary showing location of the plantation areas in the Valparai plateau (within dashed lines), some rainforest fragments (grey), and reservoirs (stippled) on the Valparai plateau.

(2,000 and 2,600 ha) within the Indira Gandhi Wildlife Sanctuary, the remaining rainforests all occur as fragments of 0.3 to 650 ha in size jointly occupying over 2000 ha, much of which is on private land. These fragments are vital for conservation as they contain significant proportions of the native fauna and they maintain landscape-level connectivity between patches. As the plantations and fragments are surrounded on all sides by protected areas that contain significant wildlife populations (Figure 1), many species move through this fragmented landscape including large mammals such as elephants (*Elephas maximus*), tigers (*Panthera tigris*), leopards (*P. pardus*), and wild dogs (*Cuon alpinus*), and birds such as Great and Malabar Grey Hornbills (bird scientific names in Appendix). The conservation of rainforest fragments is also important as corridors for these wide-ranging taxa (Kumar *et al.* 2002).

2.3 *Avifauna*

Moist forests, particularly tropical evergreen rainforest in the southern Western Ghats, is a major habitat for over 100 species of birds, including 13 endemic species (Malabar Grey Hornbill, Malabar Parakeet, Nilgiri Wood Pigeon, Grey-headed Bulbul, White-bellied Treepie, Wynaad Laughingthrush, Grey-breasted Laughingthrush, Rufous Babbler, Black-and-Orange Flycatcher, Nilgiri Flycatcher, White-bellied Blue Flycatcher, White-bellied Shortwing, Crimson-backed Sunbird). Two other restricted range-species that occur in high-altitude grasslands in this region are Nilgiri Pipit and Broad-tailed Grassbird). A number of other rare species with range largely restricted to the Western Ghats and other mountain ranges in the Indian peninsula, Sri Lanka, or the Himalaya, also occur in these tropical rainforests: e.g. Malabar Trogon, White-bellied Woodpecker, Asian Fairy Bluebird, Mountain Imperial Pigeon, Rufous-bellied Eagle, Oriental Bay Owl, Jerdon's Baza, Black-crested Baza, Ceylon Frogmouth), the last two being near-threatened species (Collar et al. 1994). Of the 230 bird species identified in the Anamalai hills (Kannan 1998, Raman 2001a) around 90 species are typical rainforest birds. Only the hornbills

receive protection under Schedule I of the Indian Wildlife Protection Act of 1972 (Anonymous 1994), although the conservation status of many other species may be equally vulnerable.

2.4 *Selection of study strata and sites*

Thirteen sites were selected for vegetation and bird sampling. This comprised of six rainforest fragments, six plantation sites, and a 'control' site that contained a relatively large and undisturbed tract of tropical rainforest in the same elevation range. Of the six fragments, three were relatively isolated in areas with tea plantations with sparse canopy whereas the remaining three adjoined shade-coffee estates with extensive canopy cover (Table 1). The plantation sites included five shade-coffee plantations differing in the canopy tree species composition and one rustic cardamom plantation maintained by a local tribal settlement under a canopy entirely consisting of native rainforest tree species (Table 1, Figure 2). Of these, three sites adjoined forest areas within the Indira Gandhi Wildlife Sanctuary, whereas the other three sites adjoined only smaller fragments that were in private lands. The 'control' site was an approximately 2,600 ha tract of tropical rainforest (Iyerpadi-Akkamalai complex) within the Indira Gandhi Wildlife Sanctuary that adjoined the plantation area on the Valparai plateau. All sites were within a restricted elevation range of 900-1,400 m containing mid-elevation tropical wet evergreen forest vegetation (Pascal 1988).

3. Methods

3.1 *Vegetation Sampling*

In 12 sites, densities of trees greater than 30 cm girth at breast height (GBH at 1.3 m) were estimated using the point-centred quarter method (PCQ, Krebs 1989). Fifteen to twenty-five PCQ plots, with successive plots spaced 50 m apart, were measured in each site, giving a sample of 60-100 trees per site. In the Siva Coffee plantation it was not possible to do PCQ plots and hence 5 m radius circular plots (N = 25 plots and 52 trees) were laid and an additional 28 random trees were identified to species. All trees in the plots were identified to species, or in a few cases to genus, using available field guides (Gamble 1935, Pascal and Ramesh 1997). Using a tape measure, distance from plot centre to the middle of the bole and GBH were recorded for each tree at each of the PCQ plots. Shrubs were counted in 25 circular plots of 2 m radius. In coffee and cardamom plantations, the number of coffee shrubs and cardamom herbs (clumps), respectively, were counted in the 2 m radius plots. In addition, the presence or absence of cane (*Calamus sp.*), bamboos, and lianas was recorded within 5 m radius plots.

Canopy and leaf litter variables were measured at 25 points, evenly spaced 25 m apart, in each site. Elevation readings were also taken at these points using an altimeter. Canopy height was measured using a rangefinder or by visual estimation. Percentage canopy cover was measured using a spherical densiometer at each of the 25 points in each site. Vertical stratification was assessed at these 25 points following Raman *et al.* (1998). The presence or absence of foliage was noted in the following height intervals (in metres): 0–1, 1–2, 2–4, 4–8, 8–16, 16–24, 24–32, and > 32, directly above and in a 0.5 m radius around each point. Leaf litter depth on the forest floor was measured using a calibrated wooden probe at each point. As ground vegetation and litter were disturbed along trails, the samples were taken 10 m away from trails into the rainforest interior.

3.2 *Bird sampling*

The emphasis was on sampling all sites for birds in a relatively uniform and efficient manner over the winter and during the main breeding season (December to May) when both migrants and residents were present in the study area. Point counts were used as a bird census method to

Table 1: Study sites selected for vegetation and bird sampling in the Valparai plateau and Indira Gandhi Wildlife Sanctuary (IGWLS), Anamalai hills.

Code	Site	Stratum	Connectivity	Description
A	Iyerpadi-Akkamalai	Control	Highest	2600 ha primary rainforest in IGWLS with very low disturbance levels
B	Andiparai	Rainforest fragment	Low	200 ha fragment surrounded largely by tea estates, connected by narrow corridor to the control site
C	Injipara	Rainforest fragment	Low	18 ha fragment, with abandoned cardamom plantation area and many exotic shade trees in the canopy, surrounded by tea estates and a logged *Eucalyptus* fuel clearing area
D	Korangumudi	Rainforest fragment	Low	56 ha abandoned cardamom plantation with highly disturbed rainforest canopy, more isolated since 2000 due to conversion of adjoining coffee to tea plantation
E	Manamboli	Rainforest fragment	High	200 ha fragment with primary rainforest in IGWLS connected to large area of forest in IGWLS
F	Puthuthottam Fragment	Rainforest fragment	High	92 ha partly with abandoned cardamom plantation and highly disturbed rainforest canopy
G	Tata Finlay Fragment	Rainforest fragment	High	33 ha moderately disturbed fragment adjoining coffee estates with mixed native and exotic tree canopy
H	Puthuthottam Coffee	Plantation	Low	Mixed canopy dominated by the exotics *Mesopsis emeni, Erythrina indica* and *Eucalyptus sp.*, with few native trees such as *Artocarpus heterophyllus*
I	Siva Coffee	Plantation	Low	Dominantly exotic tree canopy of silver oak *Grevillea robusta*
J	Tata Finlay Coffee	Plantation	Low	Mixed tree canopy of exotics such as *Erythrina indica* and *Mesopsis emeni* with existing native species such as *Cullenia exarillata, Mesua ferrea*, and *Palaquium ellipticum*
K	Surulimalai Coffee	Plantation	High	Dominantly exotic tree canopy of *Erythrina indica*
L	Old Valparai Coffee	Plantation	High	Mostly exotic tree canopy of *Erythrina indica* and *Mesopsis emeni*
M	Sankarankudi Cardamom	Plantation	High	Established by clearing ground vegetation under a completely native canopy of rainforest tree species

Figure 2: Photographs of the shade-coffee and cardamom plantation study sites and habitat structure in a degraded fragment and 'control' primary rainforest site in the Anamalai hills.

Top left: Interior of a relatively undisturbed large fragment (Manamboli); note dense canopy of trees and lianas as in primary rainforest.

Top right: Interior of a disturbed rainforest fragment (Tata Finlay) showing large canopy gaps.

Middle left: Sankarankudi cardamom plantation under a canopy of native rainforest trees.

Middle right: Puthuthottam coffee estate with mixed canopy dominated by exotics such as *Mesopsis emeni* and *Eucalyptus sp.*

Bottom: Siva coffee estate with sparse exotic silver oak *Grevillea robusta* canopy.

survey bird populations in each site. This method has been widely applied to survey birds, and is especially useful in areas with dense vegetation and difficult terrain (Karr 1981, Verner 1985, Hutto *et al.* 1986, Bibby *et al.* 1992, Ralph *et al.* 1995, Gibbons *et al.* 1996). Point count surveys were carried out during the first three hours after sunrise when bird activity was highest. Count duration of 5 min, starting from when the observer reached the point, was found suitable (Raman 2003). Points were carefully scanned for birds while entering and leaving the plot to record individuals that may have otherwise been missed. All birds seen, heard, or flying under the canopy were recorded in the following radial distance classes (in m): 0–5, 5–10, 10–15, 15–20, 20–30, 30–40, and 40–50. Densities were estimated using a fixed radius (50 m) approach as they are known to be highly correlated to variable-radius point count estimates across species (Raman 2003). Since some degraded fragment and plantation sites contained relatively more open vegetation some bias due to detectability differences may have existed and the results can only be taken as a conservative assessment of the effects of fragmentation and plantations.

In each site, 30 point count surveys (25 in Sankarankudi cardamom and 26 in Manamboli) were carried out yielding 173–308 detections and an estimated 321–633 individual birds per site. I attempted to ensure independence of data points to the extent possible by spacing out points and survey days. Successive points sampled on a given day were at least 100 m apart to avoid overlap and intermediate points in each site were sampled on different days. Although points sampled on different days overlapped to some extent, the procedure followed ensured uniform coverage of the site.

4. Analysis

4.1 *Vegetation*

For each site, tree density and basal area were calculated using the PCQ method (Krebs 1989). Average values across replicate sampling points in each site were calculated for other vegetation and site variables: shrub densities, leaf litter depth, canopy height, cover, and altitude. Vertical stratification was measured as the average number of strata with foliage across the 25 points sampled in each site. The coefficient of variation of this index reflected variation in foliage distribution across points and was used as an index of horizontal heterogeneity (following Raman *et al.* 1998). The total number of tree species recorded in the PCQ plots was recorded as a measure of tree species richness. The vegetation structure data was analysed by principal components analysis to determine fewer uncorrelated components that summarise the variation in the parameters. The factor matrix was rotated by the Varimax method to assist in interpretation and display of the results (Norušis 1990). Relationships between bird community and vegetation variables were assessed using Kendall correlations (Siegel and Castellan 1988). The distribution of foliage in different vertical strata was used to compute an index of structural dissimilarity between sites as 1–Morisita index (after Raman *et al.* 1998, Wolda 1981). The data on tree species composition was used to estimate floristic dissimilarity between sites as 1–Morisita index.

4.2 *Bird community parameters*

The 106 bird species recorded during the study were classified into rainforest and open-forest (non-rainforest birds). The rainforest species included birds that normally occurred even in mature undisturbed rainforests in Anamalais, and other rainforests in the southern Western Ghats (Raman 2001a, Ali and Ripley 1983). In contrast, open-forest species were birds that never occurred in mature, undisturbed tropical rainforest and occurred only in disturbed rainforest fragments or in naturally drier and open habitats. Analyses were performed using all species, using only rainforest species, and with only open-forest species.

Bird species richness (average per point count sample and cumulative number of species recorded) in each site was a fundamental variable of interest. The average bird abundance per point was a second major parameter of interest. In each point count sample, many bird detections were made by calls and the number of individual birds could not be counted in the field. For each species, however, information on flock sizes (a flock representing one to many individuals for this purpose) was collected separately during surveys and opportunistic observations. For every aural detection of a species, the number of individuals in the flock was randomly selected using a Monte-Carlo procedure (Raman 2003). This procedure enabled the estimation of the number of individuals in each point count sample. As only 25 point count surveys were carried out in one site, I obtained standardised estimates of bird species richness for all sites for 24 sampled points. Using the program EstimateS (Colwell 1997), I performed 100 Monte-Carlo simulations selecting 24 samples at a time (without duplicating samples) to estimate rarefaction richness, standardising for sampling effort using Coleman rarefaction curves (Coleman *et al.* 1982, Colwell 1997) and its standard deviation for each site (see Colwell and Coddington 1994 for a discussion of the utility of this approach).

Cumulative species richness and abundance (individuals/ha) of birds belonging to eight different species categories were also estimated using the point count survey data. This included Western Ghats endemics, priority species, migrants (all, forest migrants and open-forest migrants). Priority species were defined as birds of restricted-range (Stattersfield *et al.* 1998), discontinuous distribution (in rainforests of southwest India, Sri Lanka, and northeast India, Ali and Ripley 1983), or near-threatened (Collar *et al.* 1994) and did not include endemic species.

The species-abundance data from each site was used to estimate similarities between sites in bird community composition using the Morisita index (Wolda 1981). This was used to generate an ordination using multi-dimensional scaling (MDS). The difference in bird community composition between strata was tested using analysis of similarities (ANOSIM, Clarke 1993, Clarke and Warwick 1994, Clarke and Gorley 2001). The effects of stratum, connectivity, and point count (repeated measure) were assessed in a multivariate analysis of variance (MANOVA) as an alternative to repeated-measures analysis of variance (Zar 1999, p. 259).

For analysis of habitat use by species, a simple deviation index (*D*) was calculated for each habitat stratum (rainforest control, fragment, shade-coffee, and cardamom). This was computed as: D_{ij} = (Obs x_{ij} - Exp x_{ij})/(Obs x_{ij} + Exp x_{ij}), where Obs x_{ij} = the average detections of the species *i* across replicate sites in each stratum *j*, and Exp x_{ij} = $(n_j/N)*n_i$, where n_i = number of detections of species *i*, n_j = number of bird detections in habitat stratum *j*, and N = total number of detections. Values of the deviation index ranged from -1 (absence/avoidance) to +1 (presence/preference). Values $\leq$ -0.25 or $\geq$ 0.25 were considered to indicate significant avoidance or usage of the habitat stratum.

5. Results

5.1 *Vegetation structure in fragments and plantations*

Foliage profile and vegetation attributes showed distinct differences across sites. The foliage profile data on frequencies of foliage presence at different vertical strata showed highly significant variation across the four habitats: primary rainforest control, fragment, coffee, and cardamom (χ^2 = 89.92, df = 21, P < 0.001, Table 2). At the highest strata (> 32 m), control, fragment, and cardamom plantation sites had 20-24% of the points with foliage in contrast to the shade-coffee plantations, which practically lacked canopy foliage at such heights. In the lower strata, the control primary rainforest site had 46-96% of the points with foliage reflecting a moderately even distribution of foliage across height intervals. This pattern was similar in rainforest fragments except that for intermediate height strata (2-24 m), the percentage of points with foliage was 4-29% less than in primary rainforest. The foliage distribution in the plantation

sites was more uneven. The shade-coffee plantations tended to have foliage concentrated in the 0-2 m interval (coffee shrubs) and 8-16 m interval (shade trees), with less foliage in other strata. The cardamom plantation had foliage concentrated in the 0-2 m interval (cardamom plants), and in the two highest strata (tall rainforest tree species canopy), whereas the foliage in the 2-16 m intermediate strata was lower than in rainforest because small trees and shrubs were completely cleared for planting cardamom (Table 2).

Other vegetation parameters including tree density, canopy cover, and leaf litter depth tended to be highest in the primary rainforest, intermediate in fragments, and least in the plantations (Table 3) with two main exceptions. Canopy height and basal area were highest in the cardamom plantation, whereas shrub density was highest in fragments (Table 3).

Table 2: Variation in foliage distribution at different vertical levels in plantations, rainforest fragments and primary rainforest control sites in the Anamalai hills. Tabled values are means of estimates across sites in each stratum.

Vertical strata (m)	Control	Fragment	Coffee	Cardamom
>32	20.0	20.0	-	24.0
24-32	45.0	46.0	8.0	76.0
16-24	80.0	50.7	45.6	72.0
8-16	65.0	60.7	83.2	56.0
4-8	80.0	62.0	59.2	48.0
2-4	75.0	58.0	48.0	32.0
1-2	85.0	76.7	94.4	72.0
0-1	90.0	96.0	95.2	88.0

Table 3: Vegetation characteristics of the study strata in the Anamalai hills. Tabled values are means of estimates across sites in a strata and standard errors (SE) of the means.

Parameter		**Rainforest**		**Plantation**	
		Control	**Fragment**	**Coffee**	**Cardamom**
Number of sites (*N*)		1	6	5	1
Tree density (no./ha)		583.00	349.00	236.60	229.00
	SE		57.16	62.78	
Basal area (sq. m/ha)		61.38	62.28	27.83	89.54
	SE		12.76	5.74	
Altitude (m)		1304	1065	1118	1074
	SE		64.6	27.8	
Canopy cover (%)		99.40	88.71	68.79	87.72
	SE		4.38	8.72	
Canopy height (m)		26.05	23.28	15.25	28.52
	SE		1.86	1.55	
Shrub density (no./plot)		9.75	13.42	0.51	0.00
	SE		2.65	0.45	
Cut trees (no./plot)		0.40	0.74	0.00	0.00
	SE	0.15	0.20		
Vertical stratification (no. of strata)		5.35	4.71	4.14	4.68
	SE		0.29	0.51	
Horizontal heterogeneity		6.25	5.00	4.92	5.34
Leaf litter depth (cm)		7.33	4.31	3.13	2.52
	SE		0.62	0.19	0.27
Bamboo prevalence (proportion of plots)		0.05	0.05	0.00	0.00
Cane prevalence (proportion of plots)		0.40	0.12	0.00	0.00
Liana prevalence (proportion of plots)		0.45	0.24	0.00	0.00
Coffee density (no./plot)				4.88	0.00
	SE			0.37	0.00
Cardamom density (no./plot)				0.00	6.36
	SE			0.00	0.61

5.2 *Principal components analysis*

The vegetation structure data was summarised by principal components analysis of eleven key variables. The analysis extracted two components that accounted for 76.8% of the total variation in the data-set (Table 4). The first component (PC1) was significantly positively correlated to variables reflecting the density of woody plants, cane, and bamboo. The second (PC2) was positively correlated to vertical structure and canopy closure and negatively to horizontal patchiness of sites (Table 4).

The sites separate out on the two composite vegetation axes (PC1 and PC2) in a distinctive way based on vegetation differences (Figure 3). The primary rainforest and two large, relatively undisturbed rainforest fragments (Manamboli and Andiparai) form a cluster at the top right indicating a well developed woody plant community, vertical structure, and canopy closure. The plantation sites aggregate towards the left indicating poorer development of woody plants, but varied in vertical structure from poorly developed (Surulimalai and Siva coffee estates low on PC2) to well developed (Old Valparai coffee and Sankarankudi cardamom high on PC2). The remaining four fragments were structurally interspersed among plantation sites, with the more disturbed ones (Korangumudi and Injipara) being low on PC2 due to poorly developed vertical structure (Figure 3).

Table 4: Principal components analysis of vegetation variables: correlations of original variables with extracted components.

Variable	PC1	PC2
Tree density	0.801***	0.198
Basal area	0.682**	0.393
Shrub density	0.741**	0.152
Litter depth	0.849***	0.213
Bamboo prevalence	0.845***	0.032
Cane prevalence	0.956***	0.088
Liana prevalence	0.968***	0.131
Canopy cover	0.455	0.874***
Canopy height	0.442	0.569*
Vertical stratification	0.268	0.938***
Horizontal heterogeneity	0.321	-0.821***
Eigenvalue	5.519	2.929
Cumulative variance explained (%)	50.17	76.79

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.005$

5.3 *Bird community structure in plantations and fragments*

Point count sampling yielded 3299 bird detections with an estimated 5987 individuals belonging to 106 species across the 13 sites. Of the 106 bird species, 70 (66%) were rainforest birds and 36 (34%) were open-forest (non-rainforest) birds. Birds detected at least thrice during sampling comprised 78 species, including 57 (73%) rainforest and 21 (27%) open-forest species. The total numbers of bird species seen in the four main habitat strata were: 43 (primary rainforest control—one site), 95 (rainforest fragments—five sites), 76 (shade-coffee plantations—five sites), and 49 (cardamom plantation—one site).

Among the total bird species in the community in each of the four main habitat strata, the percentage of rainforest bird species was highest in the primary rainforest control (95.3%) and the cardamom plantation under natural shade (89.8%). More open-forest birds had infiltrated into rainforest fragments and shade-coffee plantations and the percentage of rainforest bird species in the community was lower at 70.5% and 59.2%, respectively, in these strata. These differences in the number of rainforest *vs.* open-forest species across the four habitat strata were statistically significant $\chi^2 = 34.1$, $df = 3$, $P < 0.001$).

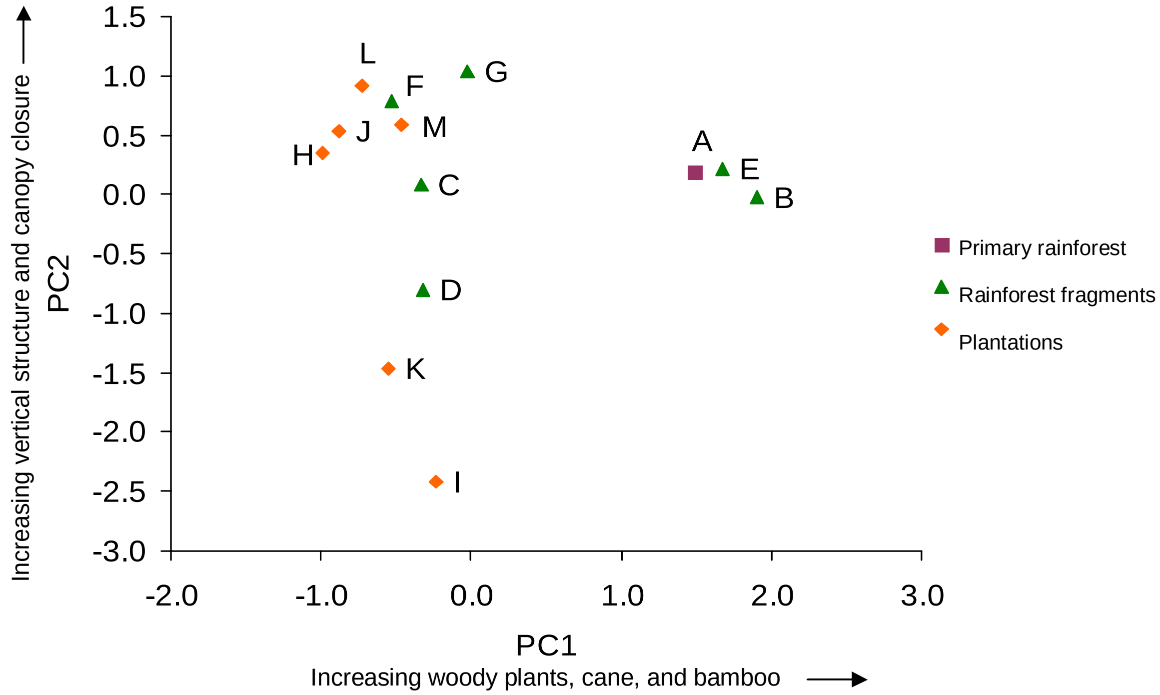

Figure 3: Ordination of primary rainforest control, fragment, and plantation sites in and around the Valparai plateau using principal components analysis of vegetation variables.

5.4 *Bird species richness and abundance: effects of habitat stratum and connectivity*

The effects of both stratum (control *vs.* rainforest fragment *vs.* plantation) and connectivity with surrounding habitat (low *vs.* high) on bird species richness and abundance were examined using MANOVA. Both stratum and connectivity had significant effects on these bird community variables ($P < 0.001$, Table 5). The repeated measure (point), which represented the replicate samples taken within each site, had no significant direct effect or 2-way or 3-way interactions with the other main effects (stratum and connectivity) in the multivariate analysis (Table 5). However, there was a significant 2-way interaction between stratum and connectivity ($P < 0.001$, Table 5).

Table 5: Results of multivariate analysis of variance (MANOVA) on the effects of habitat stratum and connectivity on total, rainforest, and open-country bird species richness and abundance in point count samples in the Anamalai hills.

Main Effects	Wilks' λ	*F*	Hypothesis *df*	Error *df*	*P*
Intercept	0.097	529.419(a)	4	228	0.000
Stratum	0.679	26.926(a)	4	228	0.000
Connectivity	0.785	7.316(a)	8	456	0.000
Point	0.665	0.846	116	908.6	0.871
2-way interactions					
Stratum × Connectivity	0.903	6.123(a)	4	228	0.000
Stratum × Point	0.694	0.753	116	908.6	0.973
Connectivity × Point	0.458	0.85	232	913.3	0.935
3-way interaction					
Stratum × Connectivity × Point	0.647	0.906	116	908.6	0.747

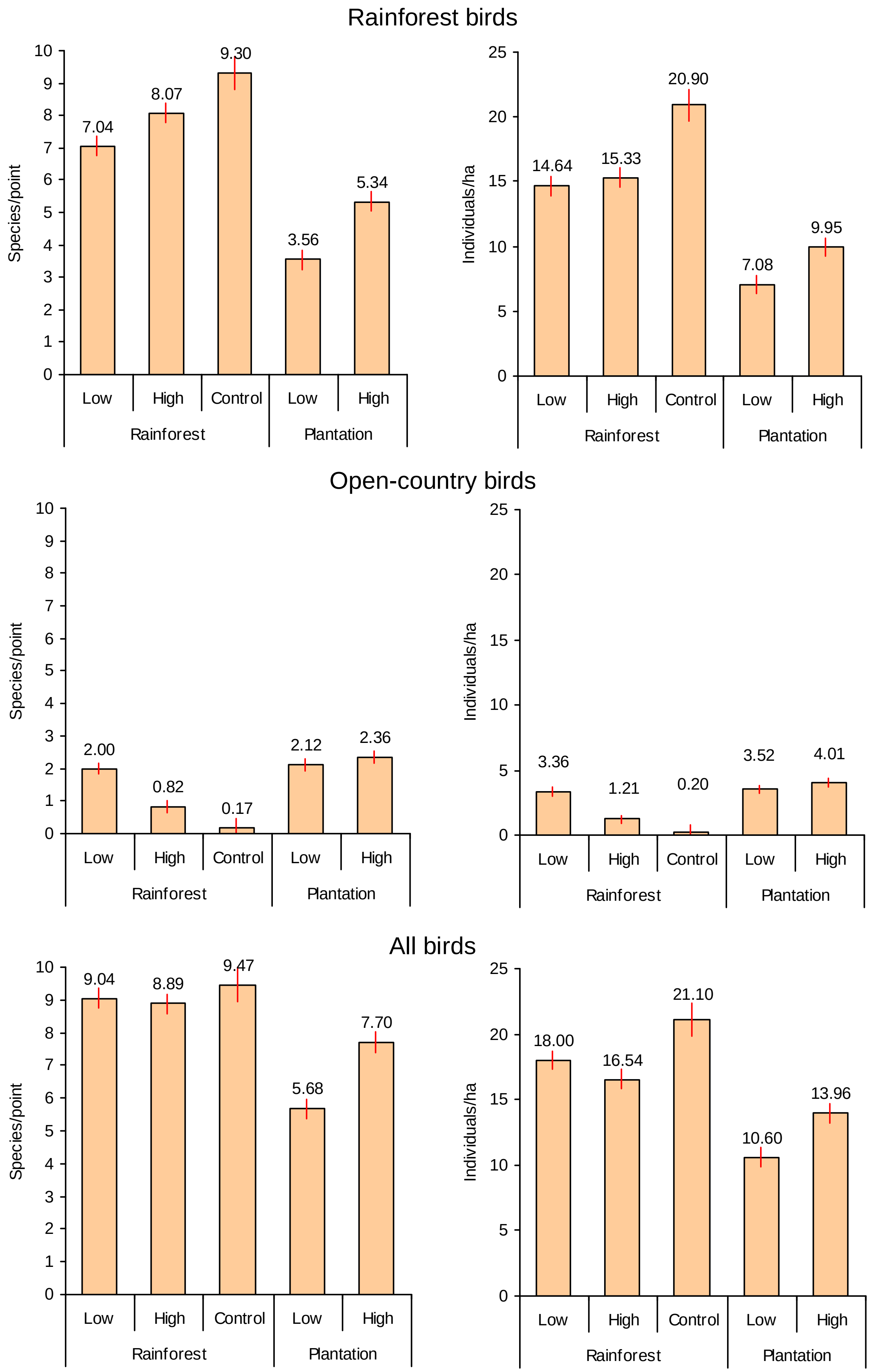

Figure 4: Effects of habitat stratum (rainforest fragment, primary rainforest control, and plantations) and connectivity (low *vs.* high) on bird community variables in the Anamalai hills. Figures illustrate estimated means per point and their standard errors for bird species richness (panels on the left) and bird abundance (panels on the right).

Bird species richness and abundance were examined for all birds combined and for the subset of rainforest and open-forest birds. Habitat stratum had a significant effect (MANOVA, $P < 0.001$) on rainforest bird species richness with plantations having per-point richness values about one-half to a third lower than in the rainforest control. Rainforest fragments had up to one-fourth lower rainforest bird species richness than control sites but the means were higher than in plantations (Figure 4). Connectivity of fragments and plantations also had a significant effect on rainforest bird species richness, with higher connectivity in the surrounding landscape resulting in higher richness and abundance ($P < 0.001$). The repeated-measure (point) did not have a significant effect on species richness ($P = 0.564$) but was significant for rainforest bird abundance ($P = 0.008$). There were no significant 2-way or 3-way interactions except for an interaction between connectivity and the repeated measure factor (point) for rainforest bird abundance ($P = 0.002$).

The results for open-forest bird species richness and abundance were similar in that both stratum and connectivity had a significant effect. However, the pattern was reversed with the primary rainforest control site having fewest, fragments intermediate, and plantations highest richness and abundance of open-forest birds (Figure 4). Connectivity also showed a converse trend with well-connected fragments having lower open-forest bird richness and abundance, although there was little difference between low- and high-connectivity plantation sites; thereby resulting in a significant interaction between connectivity and stratum for richness and abundance ($P < 0.001$). Open-forest bird species richness and abundance showed no significant direct or interaction effects with the repeated-measure factor (point).

Richness and abundance of all birds combined also showed significant effects of stratum and connectivity (as in the case of rainforest birds). However, connectivity had little effect on birds in fragments, as the positive effect on rainforest birds was compensated by the negative effect of connectivity on open-forest birds (Figure 4). Better connectivity enhanced total bird species richness and abundance in plantation sites mainly due to the positive effects it had on rainforest birds. There was thus a significant interaction effect of stratum and connectivity. There was no significant direct or interaction effect of the repeated measure (point) on total bird species richness. The repeated measure factor had a significant direct ($P = 0.006$) effect, two-way interaction with connectivity ($P = 0.001$), and 3-way interaction for total bird abundance.

5.5 *Bird community composition: effects of habitat stratum and connectivity*

Bird community similarity between sites measured by the Morisita similarity index varied substantially from a low of 0.25 (between Sankarankudi cardamom and Siva coffee) to a high of 0.91 (between primary rainforest control site and a large fragment, Andiparai, and between Surulimalai and Siva coffee estates). Multidimensional scaling ordination of sites did not reveal tight clusters (Figure 5), however, the three sites most similar (>0.60) to the primary rainforest site in terms of bird community similarity were the two large fragments (B, E), and one less disturbed rainforest fragment (E). The three more disturbed fragments (C, D, F) were intermediate between these rainforest sites and the shade-coffee plantation sites. The cardamom plantation (M) was most similar (0.78) to the relatively undisturbed Manamboli rainforest fragment (E, Figure 5).

The effects of habitat stratum and connectivity were tested using analysis of similarities (ANOSIM, using the Bray-Curtis similarity index between sites and 1000 random permutations). As sufficient replicate sites were unavailable for a simultaneous two-way analysis of both factors, each factor was analysed separately. Bird community composition differed significantly between the two habitat strata, rainforests *vs.* plantations (global $R = 0.365$, $P = 0.023$). Differences between sites differing in connectivity were not significant ($R = 0.111$, $P = 0.162$) when only two categories of connectivity was considered (low *vs.* high, where the latter includes the primary rainforest control site). The analysis was repeated with four categories: rainforests with low and

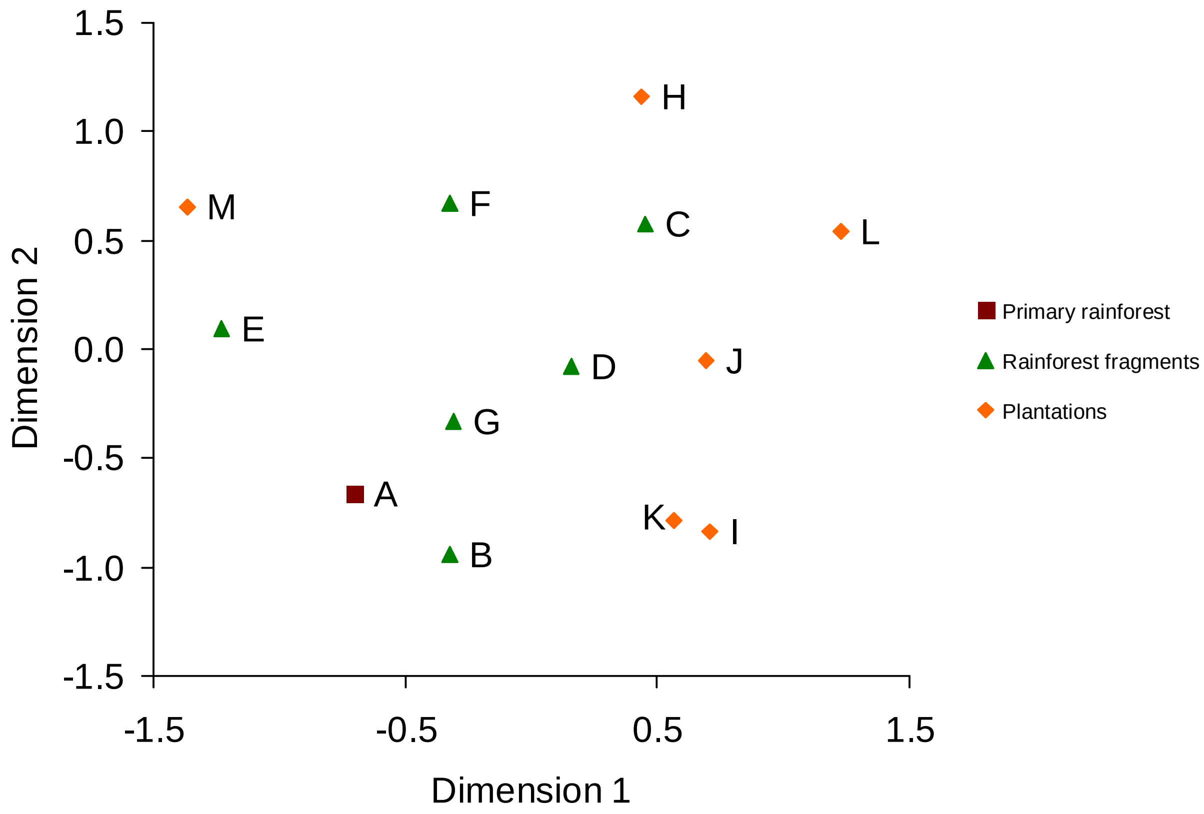

Figure 5: Bird community similarity between sites illustrated using multi-dimensional scaling (MDS) ordination. MDS was performed on the Morisita index similarity matrix (stress = 0.08).

high connectivity (RL, RH), and plantations with low and high connectivity (PL, PH). Bird community composition varied significantly across these four connectivity categories (global R = 0.314, P = 0.042). Pair-wise comparison of categories revealed significant differences only between RH and PL (R = 0.87, P = 0.029, 1 of 35 possible permutations) and near significance between RL and RH (R = 0.296, P = 0.086, 3 of 35 possible permutations) and between RL and PL (R = 0.519, P = 0.10, 1 of 10 possible permutations). Plantation sites with high connectivity did not differ significantly from rainforest sites in bird community composition (R < 0.26, P > 0.17).

5.6 *Bird species richness and abundance: species categories and correlations with vegetation components*

The species richness and abundance of various categories of bird species (all, rainforest, open-forest, endemics, priority species, rainforest migrants, and all migrants) was compared between rainforest and plantation sites. Except for open-forest birds and all migrants, values were lower in plantations than rainforests (Table 6). In particular, species richness and density of rainforest birds was 43-47% lower in plantations than in rainforest sites. Although the richness of priority species and rainforest migrants was not significantly different between the two strata, the abundance of these categories was significantly lower in plantations (Table 6).

Kendall rank-order correlation analysis was used to assess the influence of vegetation variables represented by the principal components scores of sites (PC1 and PC2). This indicated that woody plant variables, cane, liana, and bamboo, represented in PC1 had a generally positive effect on rainforest birds and endemic species and a negative effect only on total migrant species richness (Table 6). The standardised rarefaction estimate of bird species richness (in 24 point count samples) and the density of priority species showed weak positive correlations with PC1. In contrast, canopy structural variables represented on PC2 had no significant correlation with any of the bird community variables considered (Table 6).

Table 6: Cumulative species richness and abundance (individuals/ha) of various categories of birds in rainforest and shade-coffee and cardamom plantation sites in the Anamalai hills and their correlation with the vegetation principal components (PC1 and PC2).

	Rainforests		Plantations		Mann-Whitney	Kendall correlation (*T*)	
	Mean	SE	Mean	SE	*U*	PC1	PC2
Bird species richness							
All#	28.6	0.97	21.2	2.17	3.5**	0.305	0.093
Rainforest#	24.7	0.99	14.0	2.11	2.5**	0.614**	0.170
Open-country#	3.9	1.37	7.2	1.40	11.0	-0.605**	0.067
Rarefaction estimate	38.6	1.69	28.1	3.43	6.0*	0.410+	0.205
Endemic	5.0	0.31	3.2	0.65	6.0*	0.548**	0.126
Priority	11.9	0.91	8.8	1.72	10.5	0.331	0.119
Rainforest migrants	5.4	0.53	5.0	0.26	18.0	-0.075	0.165
All migrants	7.4	0.69	8.3	0.49	15.5	-0.442*	-0.100
Bird abundance							
All	22.7	0.94	15.8	1.48	3.0**	0.564**	-0.103
Rainforest	20.3	1.37	11.1	2.10	4.0*	0.641**	-0.026
Open-country	2.5	0.92	4.7	0.89	13.0	-0.374+	-0.090
Endemic	2.4	0.43	0.9	0.43	5.0*	0.564**	0.154
Priority	5.8	0.58	3.3	0.78	6.0*	0.385+	0.231
Rainforest migrants	2.4	0.16	1.6	0.20	5.0*	0.168	0.219
All migrants	3.1	0.29	2.8	0.47	14.0	-0.194	0.297

$^+P < 0.10$, $^*P < 0.05$, $^{**}P < 0.01$; # Includes only species detected >2 times in the pooled point count samples in each site. Mean and standard error (SE) were calculated from 7 rainforest and 6 plantations sites.

5.7 *Bird community composition: effects of vegetation structural and floristic similarity*

To determine the underlying influences on bird community variation between sites, Mantel tests were used to examine the effects of dissimilarity in vegetation structure and floristics (tree species composition) on bird community dissimilarity between sites. Bird community dissimilarity was strongly positively correlated to floristic dissimilarity (Mantel test, $Kr = 346$, $P < 0.001$) and weakly to structural dissimilarity ($Kr = 101$, $P = 0.092$). As structural dissimilarity and floristic dissimilarity were themselves strongly positively correlated, the effect of each variable controlling for the other was assessed with partial Mantel tests. Only floristic dissimilarity was positively correlated to bird community dissimilarity (partial $T = 0.409$, $P < 0.001$) and structural dissimilarity had a non significant effect when the effects of floristics was controlled for (partial $T = -0.057$, $P = 0.73$). Identical results were obtained when only the six plantation sites and the primary rainforest control site were included in the analysis ($N = 7$ sites, 21 pair-wise similarities).

The six plantation sites (altitude: 1,000-1,200 m) were also directly compared with the rainforest control site (1,200-1,350 m) and the largest undisturbed rainforest fragment at lower elevation (900-1,000 m). Tree species composition did not appear to have a clear relationship with bird community similarity with the rainforest control site (Figure 6). For instance, the Surulimalai and Siva coffee sites had low similarity in tree species composition (0.001 and 0.000, respectively) with the primary rainforest control site but relatively high levels of bird community similarity (0.65 and 0.61, respectively). Even the Sankarankudi cardamom plantation, which had a much higher similarity in tree species composition (0.45) with the control site, had only similar levels (0.61) of bird community similarity (Figure 6). The similarity in bird community composition with lower elevation rainforest increased more or less directly with floristic similarity except for the Surulimalai coffee plantation site (Figure 6). Notably, the shade-coffee

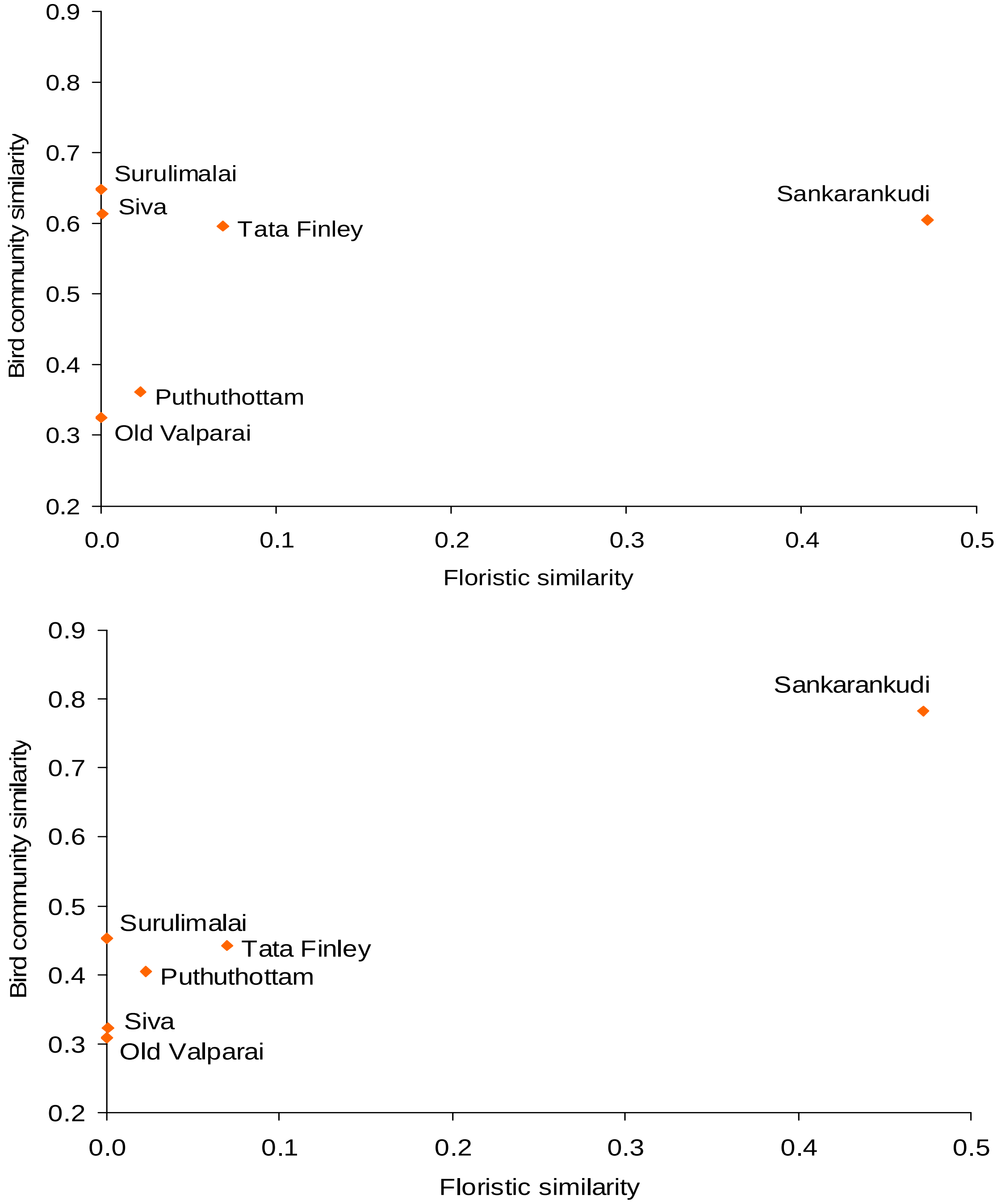

Figure 6: Bird community similarity of shade-coffee plantation sites and the Sankarankudi cardamom plantation site in relation to floristic similarity with primary rainforest control (upper panel) and with undisturbed lower elevation rainforest (lower panel).

plantation sites with close to zero floristic similarity with rainforest sites, nevertheless had between 0.33 and 0.65 bird community similarity with these sites.

5.8 *Bird species distributions in rainforests and plantations*

Analysis of species habitat use with the deviation index showed that open-forest species (residents and migrants) occurred more often than expected in shade-coffee plantations, and less often than expected in rainforest control, fragments, and cardamom plantations (Appendix). A majority of rainforest residents showed no significant preference or avoidance of rainforest

control and fragment sites, whereas their abundance tended to be negatively influenced by plantations. There were a number of exceptions, however, and many rainforest birds persisted in shade-coffee plantations, being absent or found less often than expected in rainforest control and cardamom sites (possibly because of the lower sampling intensity in these two sites). Three rainforest priority species showed significant preference for rainforest control sites (Yellow-browed Bulbul, Large Woodshrike, and Malabar Trogon). The latter species along with Little Spiderhunter and Mountain Imperial pigeon also occurred more often than expected in the cardamom plantation (Appendix). Among rainforest migrants, positive preference was shown by Grey and Forest Wagtails to shade-coffee, by Rusty-tailed Flycatcher to cardamom, and by Large-billed Leaf Warbler to the rainforest control site. Of the ten species of endemics recorded, the Crimson-backed Sunbird and White-bellied Blue Flycatcher appeared to prefer the rainforest control and cardamom plantation sites. In addition, the Nilgiri Flycatcher and Black-and-Orange Flycatcher chiefly used the rainforest control site. Shade-coffee plantations were mostly used less by endemics, except for the Malabar Grey Hornbill and Rufous Babbler. The three endemics not recorded from the control site during sampling were typically lower-elevation birds (Malabar Grey Hornbill, Malabar Parakeet) and forest edge species (Rufous Babbler). These three species have been recorded from the control site during supplementary observations.

6. Discussion

6.1 *Habitat structure and bird richness and abundance*

This study demonstrates clear differences in the vegetation among primary rainforest, fragments, shade-coffee, and cardamom plantations. Shade-coffee plantations are both structurally and floristically poorer than the other habitats with much of the foliage concentrated in the relatively uniform coffee-shrub and canopy shade-tree layers. The cardamom plantation under natural shade was floristically similar to primary rainforest in canopy tree species composition as native trees were retained as shade. This site also had a higher basal area and canopy height possibly due to the greater stature developed by shade trees after release from competition by the removal of understorey shrubs and mid-storey trees, as noted elsewhere (Parthasarathy 2001, Raman and Sukumar 2002). The vegetation characteristics of this site, chosen to represent a situation where there is minimal disturbance to the rainforest canopy trees, however cannot be generalised for cardamom plantations in the study area, as other cardamom plantations had a monoculture canopy of *Eucalyptus* sp. Fragments were similar to primary rainforest in vegetation characteristics except in having a higher shrub density, possibly due to the greater irradiance through the patchier canopy characterising these more disturbed sites.

Other major differences among strata included the absence of bamboos, canes, and lianas from the plantation sites and their lower prevalence in rainforest fragments as compared to primary rainforest. Bamboos, canes, and lianas are absent in plantations because they have been virtually eradicated in these areas during plantation maintenance operations and weeding. They were also scarce or absent in three rainforest fragments that are partly abandoned cardamom plantation areas (Puthuthottam, Injipara, Korangumudi) due to removal operations carried out in the past, but were prevalent and frequent in the other rainforest fragments.

Among these vegetation characteristics, woody vegetation variables associated with PC1 (density, basal area, leaf litter depth, cane, bamboo, liana prevalence) had the strongest influence on the species richness and density of rainforest birds, particularly endemic species. The significance of woody plant species richness and density for rainforest birds has also emerged strongly in studies on bird community structure across man-made and altered habitats in other regions of India (Raman *et al.* 1998, Raman 2001b, Raman and Sukumar 2002). Trees, shrubs, and lianas contribute to the bulk of the physical vegetation substrate within rainforest and

rainforest birds, being adapted to these substrates for foraging and nesting sites, respond positively to increasing woody vegetation density.

Vertical stratification was not strongly directly related to woody plant variables in the present study as some shade-coffee plantation sites had a relatively well-developed vertical structure relative to primary rainforest but a low diversity of native canopy tree species. In this study, vertical stratification *per se* does not significantly influence total, rainforest, or open-forest bird species richness across the set of sites considered here. Similar results were obtained across forest edge, logged, abandoned plantation, and primary rainforest sites in the Agasthyamalai hills of the Western Ghats in an earlier study (Raman and Sukumar 2002). It is possible, however, that vertical structure of vegetation may play a role in increasing bird species richness when more drastically altered habitats such as open fallows (Raman *et al.* 1998), shade-less tea plantations (Raman 2001a), or other kinds of plantations (Daniels *et al.* 1992) are included in the reckoning.

6.2 *Biological infiltration: conservation value of plantations for birds*

A simple assessment of conservation value for birds based on the number of species found using the plantation sites is insufficient. From a conservation perspective, it is important to analyse persistence and usage of these habitats by rainforest birds ('forest-affiliated avifauna', Daily *et al.* 2001) *vis-a-vis* open-forest species. That only 59–67% of the avifauna in shade-coffee plantations contained rainforest species is significant in this respect. Many typical rainforest bird species such as the Malabar Trogon, Brown-cheeked Fulvetta, White-bellied Blue Flycatcher, and Common Flameback were absent in coffee plantations, whereas others such as Great Hornbill and Dark-fronted Babbler were scarce or noted only in sites adjoining rainforest fragments. Among migrants, some species frequently noted in rainforests were absent (Western Crowned Warbler, Large-billed Leaf Warbler, Rusty-tailed Flycatcher) or scarce (Indian Blue Robin) in coffee plantations. On the other hands, habitat openings and estate roads in these plantations benefited two species of migrant wagtails (Grey and Forest Wagtails).

The process of incursion of a large number of open-forest species into rainforest fragments ('biological infiltration', Raman 2001a) is explained by alteration of habitat structure as well as the influence of the surrounding landscape. Fragments, particularly the more-disturbed ones with their patchy canopy, allow the persistence of species that thrive in open areas and weedy vegetation (e.g., Common Tailorbird, Red-whiskered Bulbul) due to changes in microhabitat and microclimate. Such open-forest species derive from the deciduous and thorn forests of the region and such infiltration into disturbed rainforests is known from many other rainforest regions (Leck 1979, Daniels *et al.* 1990, Raman *et al.* 1998, Raman 2001a,b). Dense thickets of invasive weeds such as *Lantana camara* within these fragments, with more light and warmth due to canopy openness, allow the persistence of such species that do not occur in the cool, dark, evergreen vegetation of undisturbed rainforest understorey.

Another aspect of conservation relevance to consider is whether these plantations provide resources to support populations of residents throughout the breeding and non-breeding seasons. The data obtained in this study over the main breeding season only indicate usage as it was not possible to simultaneously obtain data on breeding. Several possibilities exist that need to be verified by further research. Birds that nest on the ground or in understorey vegetation are unlikely to find adequate nesting sites in the more open coffee plantations that are frequently disturbed by humans during weeding, fertilizing, and coffee-picking operations. Plantations that consist mainly of exotic trees offer little resources for frugivorous and nectarivorous birds. Such plantations may only temporarily support frugivores such as the hornbills and Pompadour Pigeon that visit the scattered fruiting trees such as *Ficus sp., Litsea glabrata,* and *Actinodaphne angustifolia*. Nectar-seeking birds such as sunbirds, drongos, and Vernal Hanging-Parrot visited flowers of exotics such as *Eucalyptus sp.*, *Grevillea robusta*, *Erythrina mysorensis*, and even coffee bushes (Crimson-backed Sunbird) in season, besides flowers of native plants. In the more open

coffee plantations, however, an open-forest species (Purple Sunbird) was often more abundant than the endemic Crimson-backed Sunbird.

6.3 *Bird community change: effects of habitat stratum and connectivity*

An increasing number of studies show the importance of habitat in the surrounding landscape matrix on bird communities of tropical forest fragments (Stouffer and Bierregaard 1995a,b, Bierregaard and Stouffer 1997, Daily *et al.* 2001, Renjifo 2001, Luck and Daily 2003). These studies have shown that structurally complex matrices have greater potential for supporting populations of forest birds, than open areas such as pastures. In the present study, this general pattern is supported in the comparison of forest fragments that are well-connected (adjoin shade-coffee plantations) *versus* more isolated (mostly surrounded by relatively treeless tea plantations). Although, the benefit to rainforest birds by increased connectivity is easily understood, the factors inhibiting open-forest birds in fragments with increased connectivity is not directly apparent. Possible explanations include better-developed habitat structure in well-connected fragments due to absence of hard edges, competitive effects of persisting rainforest birds, or the paucity of adjoining open habitats that can act as source pools for open-forest birds.

Increased connectivity also has value for shade-coffee plantations. In the study area, there were no completely isolated (surrounded by tea estates) shade-coffee plantations and comparisons were possible only between plantations adjoining fragments and those adjoining continuous forest areas. Again, benefits of connectivity accrued to rainforest birds: more species and individuals were supported per unit area in plantations that adjoined continuous forest. If increased connectivity with forest benefits rainforest birds in shade-coffee plantations, this may also benefit plantation owners in two ways. First, the conservation value of such plantations (particularly where plantation owners wish to avail of 'eco-friendly' or 'bird-friendly' coffee certifications, Sherry 2000, Rappole *et al.* 2003) can be enhanced by maintaining patches and corridors of natural forest vegetation within plantations. Second, insectivorous bird populations may help reduce insectivory on coffee leaves. The single experimental study by Greenberg *et al.* (2000) in Guatemala showed 64-80% reduction in the number of large arthropods due to avian insectivory, although there was no difference between shade-coffee plantations with diverse shade and 'sun' coffee plantations with little shade.

Changes in bird diversity and abundance in relation to disturbance-related alteration of habitat structure is a common and direct site effect demonstrated in many studies on forest bird communities around the world (Wiens 1989). However, the nature and trajectory of the relationship between degree of habitat alteration and degree of change in community composition *per se* has been explored in fewer studies. As in other studies from Asian tropical rainforests (Raman *et al.* 1998, Raman 2001a, Raman and Sukumar 2002), floristic (tree species) composition of sites was an important predictor of bird community composition. Considerable variability existed and this is attributed to the effects of surrounding landscape. When plantation and rainforest sites were categorised by connectivity in the surrounding landscape, it was clear that the major difference in bird community composition was between rainforest sites with high connectivity and plantation sites with low connectivity. Obviously, conversion to plantations followed by isolation from forests together has a greater effect on compositional change in the bird community than either factor alone.

6.4 *Endemic and priority species*

The responses of endemic and priority species to habitat alteration were mostly idiosyncratic. In general, alteration in habitat structure, particularly woody plant variables, affected their richness and abundance, suggesting the importance of rainforest structural niches and floristic attributes for the persistence of these species, as noted in an earlier study (Raman and Sukumar 2002). As a consequence, many endemic and priority species avoided shade-coffee plantations, such as

Malabar Trogon, Mountain Imperial Pigeon, Yellow-browed Bulbul, and Common Flameback. The occurrence of Malabar Grey Hornbills in shade-coffee estates can be attributed to the retention of fruit-trees in the canopy that provide food for hornbills (Raman and Mudappa 2003). Forest-edge species, including the endemic Rufous Babbler, also persist in shade-coffee estates as they offer suitable habitat to them. Continuous rainforest emerges as an important habitat for priority species such as Malabar Trogon and Large Woodshrike and the endemic flycatchers. However, a number of priority species and endemics showed strong avoidance (as measured by the deviation index) of the rainforest control site (Appendix). This was mainly because these species were lower-elevation birds that occurred in good numbers in relatively undisturbed lower elevation rainforest but were scarce or absent in the control site available for this study.

7. Conservation Implications

This study shows that changes in the surrounding landscape affects rainforest bird communities in tropical rainforest fragments. Specifically, having shade-coffee rather than tea plantations adjoin fragments has beneficial effects on rainforest birds. Such plantations can thus promote the persistence in the entire landscape of larger populations of rainforest birds. Individual rainforest birds resident or dispersing from such sites can reduce the likelihood of chance extinction in fragments through recolonization ('rescue effect', Brown and Kodric-Brown 1977). In the study region, ongoing conversion of shade-coffee to tea plantations, driven largely by market forces, is therefore deleterious because tea plantations represent a poorer habitat for rainforest birds and because of the fallouts for fragments in the landscape. Efforts should be made to halt such changes while encouraging landowners through tax and other incentives to promote the more benign form of land use represented by shade coffee. Schemes, currently non-existent in the country, to certify shade-coffee plantations that are good for birds (Smithsonian Migratory Bird Center 1999), need to be explored as a means to promote conservation while directly translating benefits to landowners. The study also suggests that steps taken to promote the diversity of native tree species used as shade trees in coffee plantations will be beneficial from a conservation point of view. As many bird species are clearly dependent on rainforests in the landscape, it needs to be emphasised that efforts to prevent land-use conversion and promote use of a diversity of native shade tree species can only supplement, and not replace, conventional conservation efforts designed to protect and restore primary rainforests and fragments.

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APPENDIX

List of birds detected in point count sampling in rainforest and plantation sites within and adjoining the Indira Gandhi Wildlife Sanctuary in the Anamalai hills, Western Ghats. The total number of detections of each species and average detections per 25 point counts and deviations from expected detections are presented. Category codes: Res = resident, Mig = Migrant, Pri = priority species, End = endemic to Western Ghats; Habitat codes: OC = open-country, RF = rainforest.

S. No.	Habitat	Species	Category	Detections	Detections/25 point counts				Deviations			
					Control	Fragment	Coffee	Cardamom	Control	Fragment	Coffee	Cardamom
1	OC	Ashy Woodswallow *Artamus fuscus*	Res	1	-	0.14	-	-				
2	OC	Asian Koel *Eudynamus scolopocea*	Res	8	-	0.14	1.00	-	**-1.00**	**-0.61**	**0.48**	**-1.00**
3	OC	Black-headed Cuckooshrike *Coracina melanoptera*	Res	2	-	0.14	0.14	-				
4	OC	Black-rumped Flameback *Dinopium benghalense*	Res	6	-	0.28	0.57	-	**-1.00**	-0.22	**0.37**	**-1.00**
5	OC	Blue-winged Leafbird *Chloropsis cochinchinensis*	Res	1	-	-	0.14	-				
6	OC	Brown-capped Pygmy Woodpecker *Dendrocopos nanus*	Res	6	-	0.57	0.29	-	**-1.00**	0.12	0.04	**-1.00**
7	OC	Chestnut-headed Bee-eater *Merops leschenaulti*	Res	10	0.83	0.14	1.00	1.00	0.05	**-0.68**	**0.39**	0.11
8	OC	Chestnut-tailed Starling *Sturnus malabaricus*	Res	2	-	0.28	-	-				
9	OC	Common Hoopoe *Upupa epops*	Res	2	-	0.14	0.14	-				
10	OC	Common Iora *Aegithina tiphia*	Res	10	-	0.85	0.29	2.00	**-1.00**	0.07	-0.21	**0.43**
11	OC	Common Tailorbird *Orthotomus sutorius*	Res	62	-	2.13	6.71	-	**-1.00**	**-0.37**	**0.42**	**-1.00**
12	OC	Greater Coucal *Centropus sinensis*	Res	23	-	0.71	2.57	-	**-1.00**	**-0.41**	**0.43**	**-1.00**
13	OC	Grey-bellied Cuckoo *Cacomantis passerinus*	Res	1	-	0.14	-	-				
14	OC	Grey-breasted Prinia *Prinia hodgsonii*	Res	18	-	0.85	1.71	-	**-1.00**	-0.22	**0.37**	**-1.00**
15	OC	Jungle Myna *Acridotheres fuscus*	Res	2	-	-	0.29	-				
16	OC	Kestrel *Falco tinnunculus*	Res	1	-	-	0.14	-				
17	OC	Large-billed Crow *Corvus macrorhynchus*	Res	44	-	3.13	3.00	1.00	**-1.00**	-0.02	0.21	**-0.56**
18	OC	Oriental Magpie Robin *Copsychus saularis*	Res	27	-	1.14	2.71	-	**-1.00**	**-0.27**	**0.39**	**-1.00**
19	OC	Pied Cuckoo *Clamator jacobinus*	Res	1	-	-	0.14	-				
20	OC	Plum-headed Parakeet *Psittacula cyanocephala*	Res	34	-	2.70	2.14	-	**-1.00**	0.04	0.18	**-1.00**
21	OC	Purple Sunbird *Nectarinia asiatica*	Res	27	-	0.57	3.29	-	**-1.00**	**-0.56**	**0.47**	**-1.00**
22	OC	Red-whiskered Bulbul *Pycnonotus jocusus*	Res	151	-	7.81	13.29	3.00	**-1.00**	-0.18	**0.33**	**-0.60**
23	OC	Shikra *Accipiter badius*	Res	5	-	0.57	0.14	-	**-1.00**	0.21	-0.21	**-1.00**

S. No.	Habitat	Species	Category	Detections	Detections/25 point counts				Deviations			
					Control	Fragment	Coffee	Cardamom	Control	Fragment	Coffee	Cardamom
24	OC	Small Minivet *Pericrocotus cinnamomeus*	Res	4	-	0.28	0.29	-				
25	OC	Spotted Dove *Streptopelia chinensis*	Resident	2	-	0.14	0.14	-				
26	OC	Streak-throated Woodpecker *Picus xanthopygaeus*	Res	1	-	0.14	-	-				
27	OC	White-breasted Waterhen *Amaurornis phoenicurus*	Res	2	-	-	0.29	-				
28	OC	White-throated Kingfisher *Halcyon smyrnensis*	Res	4	-	0.14	0.43	-				
29	OC	Asian Brown Flycatcher *Muscicapa dauurica*	Mig	11	-	0.85	0.71	-	**-1.00**	0.02	0.19	**-1.00**
30	OC	Black-naped Oriole *Oriolus chinensis*	Mig	1	-	-	0.14	-				
31	OC	Blue-capped Rock Thrush *Monticola cinclorhynchus*	Mig	1	-	-	0.14	-				
32	OC	Blyth's Reed Warbler *Acrocephalus dumetorum*	Mig	206	3.33	12.64	14.86	9.00	**-0.65**	-0.09	0.24	**-0.29**
33	OC	Brown Shrike *Lanius cristatus*	Mig	14	-	0.99	1.00	-	**-1.00**	-0.02	0.24	**-1.00**
34	OC	Common Rosefinch *Carpodacus erythrinus*	Mig	9	-	0.57	0.71	-	**-1.00**	-0.08	**0.29**	**-1.00**
35	OC	Eurasian Golden Oriole *Oriolus oriolus*	Mig	10	-	0.28	1.14	-	**-1.00**	**-0.44**	**0.44**	**-1.00**
36	OC	Red-throated Flycatcher *Muscicapa parva*	Mig	1	-	-	0.14	-				
37	RF	Asian Paradise-Flycatcher *Terpsiphone paradisi*	Res	15	0.83	0.99	1.00	-	-0.16	-0.05	0.20	**-1.00**
38	RF	Bar-winged Flycatcher-Shrike *Hemipus picatus*	Res	23	5.83	1.85	0.29	1.00	**0.54**	0.04	**-0.56**	**-0.29**
39	RF	Besra *Accipiter virgatus*	Res	4	0.83	0.43	-	-				
40	RF	Black-lored Tit *Parus xanthogenys*	Res	23	-	2.27	0.71	2.00	**-1.00**	0.14	-0.17	0.05
41	RF	Black-naped Monarch *Hypothymis azurea*	Res	31	5.00	2.41	-	8.00	**0.36**	0.03	**-1.00**	**0.53**
42	RF	Blue-bearded Bee-eater *Nyctyornis athertoni*	Res	1	-	0.14	-	-				
43	RF	Bronzed Drongo *Dicrurus aeneus*	Res	18	-	1.99	0.57	-	**-1.00**	0.20	-0.16	**-1.00**
44	RF	Brown-cheeked Fulvetta *Alcippe poioicephala*	Res	48	10.00	4.69	-	3.00	**0.47**	0.14	**-1.00**	-0.12
45	RF	Crested Serpent Eagle *Spilornis cheela*	Res	3	-	0.14	0.29	-				
46	RF	Drongo Cuckoo *Surniculus lugubris*	Res	1	-	0.14	-	-				
47	RF	Emerald Dove *Chalcophaps indica*	Res	6	-	0.85	-	-	**-1.00**	**0.32**	**-1.00**	**-1.00**
48	RF	Eurasian Blackbird *Turdus merula*	Res	16	0.83	1.42	0.71	-	-0.19	0.09	0.01	**-1.00**
49	RF	Golden-fronted Leafbird *Chloropsis aurifrons*	Res	7	-	0.28	0.71	-	**-1.00**	**-0.29**	**0.40**	**-1.00**
50	RF	Greater Flameback *Chrysocolaptes lucidus*	Res	25	1.67	2.13	0.86	2.00	-0.07	0.07	-0.13	0.00
51	RF	Greater Racket-tailed Drongo *Dicrurus paradiseus*	Res	29	0.83	2.70	0.14	8.00	**-0.45**	0.11	**-0.80**	**0.55**
52	RF	Grey Junglefowl *Gallus sonneratii*	Res	7	-	0.57	0.29	1.00	**-1.00**	0.05	-0.04	**0.29**
53	RF	Grey-headed Canary Flycatcher *Culicicapa ceylonensis*	Res	55	13.33	3.41	-	15.00	**0.52**	-0.09	**-1.00**	**0.55**
54	RF	Hill Myna *Gracula religiosa*	Res	62	5.83	3.98	1.86	14.00	0.11	-0.07	-0.19	**0.48**

S. No.	Habitat	Species	Category	Detections	Detections/25 point counts				Deviations			
					Control	Fragment	Coffee	Cardamom	Control	Fragment	Coffee	Cardamom
55	RF	Indian Scimitar Babbler *Pomatorhinus horsfieldii*	Res	73	5.00	5.97	3.29	2.00	-0.05	0.05	0.01	**-0.49**
56	RF	Orange-headed Thrush *Zoothera citrina*	Res	47	1.67	4.26	1.86	2.00	**-0.36**	0.10	-0.06	**-0.30**
57	RF	Oriental Honey-Buzzard *Pemis ptilorhynchus*	Res	1	-	0.14	-	-				
58	RF	Oriental White-Eye *Zosterops palpebrosus*	Res	119	14.17	7.67	6.57	2.00	0.22	-0.07	0.11	**-0.65**
59	RF	Pompadour Green Pigeon *Treron pompadora*	Res	17	0.83	0.85	0.57	6.00	-0.22	-0.19	-0.14	**0.63**
60	RF	Puff-throated Babbler *pellorneum ruficeps*	Res	35	3.33	3.27	0.71	3.00	0.11	0.12	**-0.37**	0.04
61	RF	Red Spurfowl *Galloperdix spadicea*	Res	9	0.83	0.99	0.14	-	0.10	0.20	**-0.47**	**-1.00**
62	RF	Scarlet Minivet *Pericrocotus flammeus*	Res	70	2.50	5.82	2.71	7.00	**-0.36**	0.06	-0.06	0.11
63	RF	Velvet-fronted Nuthatch *Sitta frontalis*	Res	66	5.00	5.54	2.29	5.00	0.00	0.06	-0.12	-0.02
64	RF	Asian Fairy Bluebird *Irena puella*	Pri	38	4.17	2.56	0.29	13.00	0.18	-0.05	**-0.71**	**0.62**
65	RF	Black Bulbul *Hypsipetes leucocephalus*	Pri	33	9.17	2.98	-	1.00	**0.57**	0.10	**-1.00**	**-0.45**
66	RF	Black-crested Bulbul *Pycnonotus melanicterus*	Pri	12	-	1.42	0.14	1.00	**-1.00**	0.23	**-0.58**	0.02
67	RF	Common Flameback *Dinopium javanense*	Pri	6	0.83	0.57	-	1.00	**0.29**	0.12	**-1.00**	**0.35**
68	RF	Crimson-fronted Barbet *Megalaima rubricapilla*	Pri	20	-	1.42	1.43	-	**-1.00**	-0.02	0.24	**-1.00**
69	RF	Dark-fronted Babbler *Rhopocichla atriceps*	Pri	21	2.50	2.27	0.14	1.00	0.22	0.19	**-0.73**	**-0.25**
70	RF	Dollarbird *Eurystomus orientalis*	Pri	1	-	-	0.14	-				
71	RF	Great Hornbill *Buceros bicornis*	Pri	2	0.83	-	0.14	-				
72	RF	Heart-spotted Woodpecker *Hemicircus canente*	Pri	4	0.83	0.14	-	2.00				
73	RF	Large Woodshrike *Tephrodornis gularis*	Pri	17	3.33	0.85	0.86	1.00	**0.44**	-0.19	0.07	-0.15
74	RF	Little Spiderhunter *Arachnothera longirostra*	Pri	69	3.33	7.10	0.14	14.00	-0.22	0.16	**-0.91**	**0.44**
75	RF	Malabar Trogon *Harpactes fasciatus*	Pri	5	0.83	0.43	-	1.00	**0.37**	0.07	**-1.00**	**0.43**
76	RF	Malabar Whistling Thrush *Myophonus horsfieldii*	Pri	83	8.33	7.10	2.00	9.00	0.14	0.07	**-0.29**	0.15
77	RF	Mountain Imperial Pigeon *Ducula badia*	Pri	22	2.50	1.42	0.14	8.00	0.20	-0.07	**-0.74**	**0.64**
78	RF	Plain Flowerpecker *Dicaeum concolor*	Pri	290	16.67	20.74	15.71	14.00	-0.14	-0.02	0.10	-0.24
79	RF	Rufous Woodpecker *Celeus brachyurus*	Pri	2	-	0.14	-	1.00				
80	RF	Vernal Hanging Parrot *Loriculus vernalis*	Pri	70	6.67	4.83	3.00	7.00	0.11	-0.03	-0.01	0.11
81	RF	White-bellied Woodpecker Dryocopus javensis	Pri	1	-	0.14	-	-				
82	RF	White-cheeked Barbet *Megalaima viridis*	Pri	125	11.67	8.95	5.86	7.00	0.10	-0.02	0.03	-0.17
83	RF	Yellow-browed Bulbul *Iole indica*	Pri	102	15.83	9.38	1.00	10.00	**0.34**	0.11	**-0.64**	0.10
84	RF	Ashy Drongo *Dicrurus leucophaeus*	Mig	35	-	2.98	2.00	-	**-1.00**	0.07	0.13	**-1.00**
85	RF	Brown-breasted Flycatcher *Muscicapa muttui*	Mig	3	-	0.14	0.14	1.00				

S. No.	Habitat	Species	Category	Detections	Detections/25 point counts				Deviations			
					Control	Fragment	Coffee	Cardamom	Control	Fragment	Coffee	Cardamom
86	RF	Forest Wagtail *Dendronanthus indicus*	Mig	24	-	0.57	2.71	1.00	**-1.00**	**-0.51**	**0.44**	**-0.31**
87	RF	Greenish Warbler *Phylloscopus trochiloides*	Mig	306	23.33	21.73	15.71	15.00	0.00	-0.02	0.08	-0.24
88	RF	Grey Wagtail *Motacilla cinerea*	Mig	15	-	0.28	1.86	-	**-1.00**	**-0.59**	**0.47**	**-1.00**
89	RF	Indian Blue Robin *Luscinia brunnea*	Mig	48	0.83	5.40	0.71	4.00	**-0.63**	0.21	**-0.50**	0.02
90	RF	Indian Pitta *Pitta brachyura*	Mig	1	-	-	0.14	-				
91	RF	Large Hawk Cuckoo *Hierococcyx sparverioides*	Mig	2	-	0.14	0.14	-				
92	RF	Large-billed Leaf Warbler *Phylloscopus magnirostris*	Mig	100	17.50	9.52	-	12.00	**0.39**	0.13	**-1.00**	0.20
93	RF	Pied Thrush *Zoothera wardii*	Mig	2	-	0.28	-	-				
94	RF	Rusty-tailed Flycatcher *Muscicapa ruficauda*	Mig	19	-	2.27	-	3.00	**-1.00**	0.24	**-1.00**	**0.33**
95	RF	Verditer Flycatcher *Eumyias thalassina*	Mig	1	-	0.14	-	-				
96	RF	Western Crowned Warbler *Phylloscopus occipitalis*	Mig	4	0.83	0.43	-	-				
97	RF	Black-and-Orange Flycatcher *Ficedula nigrorufa*	End	10	5.83	0.28	-	1.00	**0.77**	**-0.44**	**-1.00**	0.11
98	RF	Crimson-backed Sunbird *Nectarinia minima*	End	156	22.50	12.36	2.29	26.00	**0.31**	0.03	**-0.50**	**0.35**
99	RF	Grey-headed Bulbul *Pycnonotus priocephalus*	End	1	-	0.14	-	-				
100	RF	Malabar Grey Hornbill *Ocyceros griseus*	End	33	-	2.41	2.14	1.00	**-1.00**	-0.01	0.19	**-0.45**
101	RF	Malabar Parakeet *Psittacula columboides*	End	30	-	3.27	0.71	2.00	**-1.00**	0.19	**-0.30**	-0.09
102	RF	Nilgiri Flycatcher *Eumyias albicaudata*	End	29	6.67	2.84	0.14	-	**0.50**	0.14	**-0.80**	**-1.00**
103	RF	Rufous Babbler *Turdoides subrufus*	End	10	-	0.85	0.57	-	**-1.00**	0.07	0.13	**-1.00**
104	RF	White-bellied Blue Flycatcher *Cyornis pallipes*	End	21	3.33	1.42	-	7.00	**0.35**	-0.04	**-1.00**	**0.62**
105	RF	White-bellied Treepie *Dendrocitta leucogastra*	End	3	-	0.43	-	-				
106	RF	Wynaad Laughingthrush *Garrulax delesserti*	End	2	-	0.14	-	1.00				